SEWAGE SLUDGE TREATMENT BY MEMBRANE ANAEROBIC SYSTEM (MAS)

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A thesis in fulfilment of the

requirement for the award of the degree of

Bachelor of Chemical Engineering

Faculty of Chemical & Natural Resources Engineering

Universiti Malaysia Pahang

December 2010

ABSTRACT

The performance of Membrane Anaerobic System (MAS) was investigated in treating raw sewage sludge. Certain parameters were investigated such as Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Total Suspended Solid (TSS) and pH. MAS consist of Ultrafiltration membrane for solid-liquid separation with 1.5 – 2.0 bar of operational pressure. An enrichment culture of methanogenic bacteria was developed in the digester when seed sludge was feed into 50 L digester. The raw sewage sludge was obtained from the Indah Water Municipal Treatment Plant at Taman Seri Mahkota Aman KUN 112. The digester operates 5 hours per day for 11 days. The conventional method to treat raw sewage sludge is by using Aerobic and Anaerobic digestion. Aerobic digestion is expensive method since it used oxygen and anaerobic digestion required large area and slower process. As an alternative method, MAS was being invented and offer great advantages. In this study, 70 % of methane gas was produce and removal efficiency of COD was up 60.74% to 97.24%.MAS treatment efficiency is greatly affected by pH, temperature, organic loading rate (OLR) and hydraulic retention time (HRT).MAS was found to be the biological treatment system to achieve a high COD removal in a short period of time and the effluent colour is more clear. Thus make MAS is a good alternative for treating wastewater.

ABSTRAK

Prestasi Membran anaerobik System (MAS) telah diselidiki dalam merawat kumbahan sisa mentah. Parameter tertentu telah diteliti seperti Permintaan Oksigen Kimia (COD), Permintaan ooksigen Biokimia (BOD), Keseluruhan Tahanan pepejal (TSS) dan pH. MAS terdiri daripada membran ultrafiltrasi untuk pemisahan padat-cair dengan 1,5-2,0 bar tekanan operasi. Bakteria metanogen dikultur pada reaktor ketika lumpur benih dimasukkan ke dalam reactor 50L. Lumpur sisa baku diperolehi daripada Indah Water Treatment Plant Bandar di Taman Seri Mahkota Aman KUN 112.Reaktor beroperasi selama 5 jam sehari untuk 11 hari. Kaedah konvensional untuk merawat lumpur sisa baku adalah dengan menggunakan aerobik dan pencernaan anaerobik. Pencernaan Aerobik adalah kaedah mahal kerana menggunakan oksigen dan pencernaan anaerobik memerlukan kawasan yang luas dan prosesnya lebih lambat. Sebagai kaedah alternatif, MAS telah dicipta dan menawarkan banyak kelebihan. Dalam kajian ini, 70% gas metana telah dihasilkan dan kecekapan removal COD dari 60.74% menjadi 97.24%.Kecekapan rawatan MAS sangat dipengaruhi oleh pH, suhu, laju beban organik (OLR) dan masa retensi hidrolik (HRT) .MAS telah dibuktikan menjadi sistem pemprosesan biologi yang baik dan dapat mencapai COD tinggi dalam masa yang singkat dan warna efluen lebih jelas. Jadi,MAS adalah alternatif yang baik untuk memproses sisa cair.

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LIST OF ABBREVIATION / SYMBOLS

MAS	Membrane Anaerobic System
COD	Chemical Oxygen Demand
BOD	Biochemical Oxygen Demand
TSS	Total Suspended Solid
CH_4	Methane Gas
H_2O	Water
CO_2	Carbon Dioxide
NH_3	Ammonia
VFA	Volatile Fatty Acid
HCO_3	Bicarbonate
HRT	Hyraulic Retention Time
PVC	Polyvinylchloride
CH_3OH	Methanol
CH_2O	Formaldehyde
CH_3NO_2	Nitromethane
CH_3Cl	Chloroform
CCl_4	Carbon Tetracholide
CUF	Cross Flow Ultrafiltration
NaOH	Sodium Hydroxide
MWCU	Molecilar Weight Cut-Off
OLR	Organic Loading Rate
pKa	Dissociation Constant

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The sewage sludge treatment by Membrane Anaerobic System (MAS) currently used to treat the organic waste from any treatment plant. This kind of waste treatment presents the great advantages since it not used any chemicals like strong acids that can be harmful to people and animals and also it can reduce the amount of organic matter which might otherwise be destined to be land filled. The process is also simple, less expensive and it will produce useful by-products which is methane gas, a valuable gas nowadays. Methane gas are use to generate electricity, produce cooking gases, and also it can replace the energy derived from fossil fuels, and hence reduce emissions of greenhouse gasses.

The first discovery was reported in the seventeenth century by Robert Boyle and Stephen Hale, who noted that flammable gas was released by disturbing the sediment of streams and lakes. Through scientific research anaerobic digestion gained academic recognition in the 1930s and it lead the discovery of anaerobic bacteria. As the time goes by, anaerobic digestion are widely use. It is not only to treat manure but also the waste from treatment plant.

Anaerobic digestion is a process in which microorganisms digest biodegradable material with little or in the absence of oxygen. The mesophilic bacteria were place into the reactor which temperature is between 35^0C-45^0C. Then the sewage sludge is entering the reactor, and the digestion process occurs. The digestion process begins with bacterial hydrolysis of the input materials in order to break down insoluble organic polymers such as carbohydrates and make them available for other bacteria. Acidogenic bacteria then convert the sugars and amino acids into carbon dioxide, hydrogen, ammonia, and organic acids. Acetogenic bacteria then convert these resulting organic acids into acetic acid, along with additional ammonia, hydrogen, and carbon dioxide. Methanogens finally are able to convert these products to methane and carbon dioxide. The final product is methane, carbon dioxide and also the treated sewage sludge (Metcalf &Eddy.Inc, 2003)

When a liquid sludge is produced, further treatment may be required to make it suitable for final disposal. Typically, the water in the sludge is been remove to reduce the volumes transported off-site for disposal. Processes of removing water content include lagooning in drying beds to produce a cake; pressing, where sludge is mechanically filtered, often through cloth screens to produce a firm cake; and centrifugation where the sludge is thickened by centrifugally separating the solid and liquid. Sludge can be disposed of by liquid injection to land or by disposal in a landfill. In certain country, after centrifugation, the sludge is then completely dried by sunlight (Howard S. Peavy et al, 1985). The nutrient rich biosolids are then provided to farmer free-of-charge to use as a natural fertilizer (M. H. Wonga et al, 1995). This method can reduce the amount of landfill generated by the process each year.

1.2 PROBLEM STATEMENT

- The conventional techniques take times to accomplish.
- Expensive and high cost for raw materials treatment.
- High demand.
- Limited resources.

1.3 OBJECTIVE

In this research, there are few objectives to be fulfilled. Those are:

- To evaluate the anaerobic transformation of sewage sludge to methane gas in a membrane anaerobic system (MAS).
- To experimentally assess the factors influencing anaerobic digester performance such as pH, chemical oxygen demand(COD),biological oxygen demand(BOD), and total suspended solid(TSS).
- Overall performance of membrane anaerobic system (MAS).

1.4 SCOPE OF STUDY

To accomplish the objectives of this study, these are the scopes to be focused on:

- A laboratory digester was scaled membrane anaerobic system (MAS) with an effective 50 litre volume was designed and used to treat raw sewage sludge.

- Enrichment cultures of methanogenic bacteria were developed in the digester.

- To study the parameters that affects the performance of MAS such as pH, Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), and Total Suspended Solid (TSS).

- Last but not least, to measured the percentage of methane gas production by using J-Tube gas Analyzer.

1.5 RATIONAL& SIGNIFICANCE

- Energy saving.

- Less expensive treatment.

- Environmental friendly.

- Can reduce the organic matter in the sewage sludge.

- Production of methane gas (CH_4) from waste.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

There are mainly two ways to treat raw sewage sludge. First with aerobic process and second is anaerobic process. Aerobic process is the process in which the microorganisms breakdown all the biodegradable materials with presence of oxygen. This process is quite expensive treatment because it uses oxygen in the process of treating sewage sludge. Since the percentage of raw sewage sludge disposal is increasing daily so this technique is not convenient anymore. People started to find other alternative ways to treat their raw sewage sludge and found that, anaerobic process is the best way to treat their raw sewage sludge.

Anaerobic process is the process in which microorganisms will breakdown all the biodegradable materials with little or absence of oxygen. This process used anaerobic bacteria. Not much country used this process, only a few countries like German used this process. This process offers several advantages and also disadvantages, which are:

- Less energy required
- Less biological sludge produced
- Lower nutrient demand
- Methane production: Providing potential energy source with possible revenue both from sale of the energy, and benefit from government tax, and (Kyoto agreement) CDM etc. payments arising from renewable fuels/non-fossil fuel incentives
- Methane production: Anaerobic digestion contributes to reducing greenhouse gases by reducing demand for fossil fuels
- Smaller reactor volume required
- Biomass acclimatisation allows most organic compounds to be transformed
- Rapid response to substrate addition after long periods without feeding
- End product can be potentially saleable products biogas, soil conditioner and a liquid fertiliser.
- Process more effectively provides sanitisation/removal of diseases.

Several disadvantages of anaerobic process:

- Longer start-up time to develop necessary biomass inventory
- May require alkalinity and/or specific ion addition
- May require further treatment with an aerobic treatment process to meet discharge requirements
- Biological nitrogen and phosphorus removal is not possible
- Much more sensitive to the adverse effect of lower temperatures on reaction rates
- May need heating (often by utilisation of process gas) to achieve adequate reaction rates
- May be more less stable after ‘toxic shock’(eg after upsets due to toxic substances in the feed)
- Increased potential for production of odours and corrosive gases.
- Hazards arise from explosion. (In the EU, such additional Health & Safety Regulations as the ATEX Directive, and possibly also Gas Institute Regulations will require various compliance measures to be applied for AD.)

- Anaerobic treatment is not effective for treatment of methanogenic landfill leachate, it may (rarely) be efficacious for the early stage leachate production period while the waste is still Acetogenic.

All those weaknesses drive people to find an alternative ways to improve the system. Recently, there have an alternative ways to treat sewage, which is Membrane Anaerobic System (MAS).This system is a combination of membrane separation technology and anaerobic process. This system has overcome several problem that face before such as it is only required small treatment area and the most important is it is only takes a short period of time to treat sewage sludge compared with conventional technique and this process can produce methane gas (CH_4) .

2.2 RAW SEWAGE SLUDGE

Raw sewage sludge is a muddy like, yellowish colour and has a bad smell. It is slurry with water content and rich in nutrient such as organic matter derived from human, animal and food wastes. Other constituents are trace contamination mainly from industrial effluents and bacteria. (B.R.Gurjar,2001). Since raw sewage sludge contain hazardous materials to human, so it has to treat before it can dispose to the landfill site. Basically, there are 2 methods to treat the sewage sludge which are aerobic process and anaerobic process than only it can be dispose. Before dispose, it will undergo thickening and dewatering process to increase the solid concentration of sludge and decrease its volume by removing a portion of the water. (IzrailS.Turovskiy et al, 2006).

2.3 AEROBIC DIGESTION

Aerobic digestion is the conventional technique to treat a wide range of sludge. It is a process of oxidation and decomposition of the organic part of the sludge by microorganism in special open or enclosed tank with the presence of oxygen (IzrailS.Turovskiy et al, 2006).The process produce stable product. The stable product means the sludge is reduce in mass, volume, pathogenic organisms and does not have bad smell. This process has advantages and disadvantages. The major advantages of this process are odourless and easier to operate. The major disadvantage is the operating cost higher since it used oxygen in this process. So, people start to find alternative method in order to reduce the cost for sludge treatment.

2.3.1 PROCESS THEORY

Aerobic digestion is a continuous process. When the soluble substrate is completely been consumed by the bacteria, the bacteria begin to consume their protoplasm to obtain the energy for cell maintenance. This phenomenon is called *endogenous respiration*. This is the major reaction in aerobic process. The cell is oxidized aerobically to produce carbon dioxide (CO_2), water (H_2O) and ammonia (NH_3) (IzrailS.Turovskiy et al,2006).

2.3.2 CONVENTIONAL AEROBIC DIGESTION

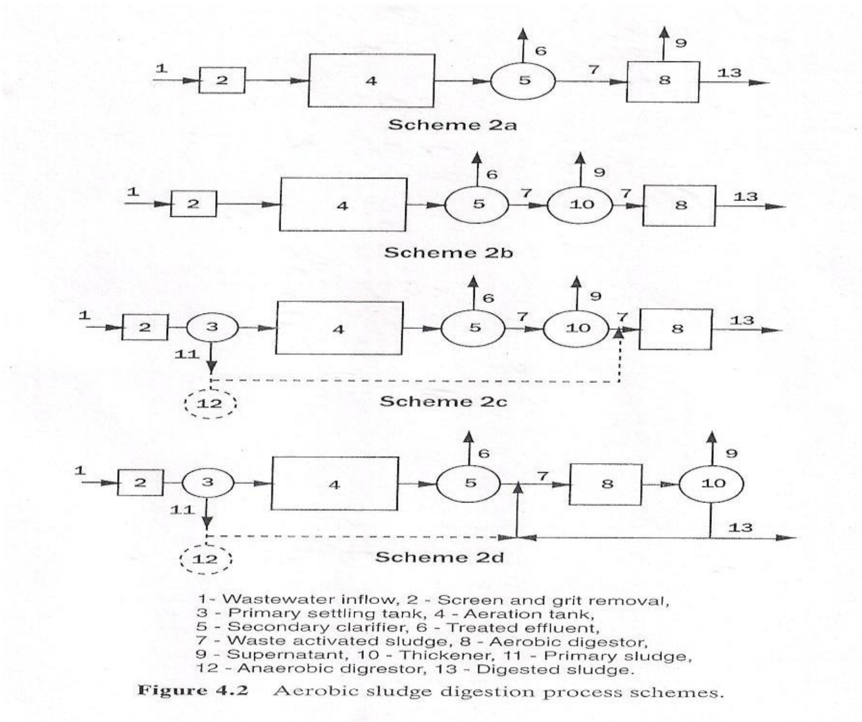

Figure 2.1: Aerobic Sludge Digestion Process Scheme Taken from (IzrailS.Turovskiy et al, 2006)

For wastewater treatment plant without primary settling tank, scheme 2a and 2b is recommended. In scheme 2a, the activated sludge goes to the aerobic digester directly from secondary clarifier. The sludge goes to the digester after preliminary concentration in a sludge thickener. Scheme 2c and 2d are the common process used to treat raw sewage sludge from small to medium size wastewater treatment plant. In 2c, thickened secondary sludge is combined with primary sludge and discharged to the digester. For 2d, combined primary and unthickened secondary sludge is digested first and thickened in a thickener. (IzrailS.Turovskiy et al,2006)

2.4 ANAEROBIC DIGESTION

Anaerobic digester has been used as an alternative way to treat raw sewage sludge. It is the process by which organic materials in this case is raw sewage sludge is fermented or has been breakdown by bacteria in the absence of oxygen (LudovicoSpinosa et al,2001) This process basically do the same this as aerobic process did, like produce stable sewage sludge, but the different between this 2 methods is the by-products. In anaerobic process, it will produce methane gas (CH_4) as it by-product but in aerobic process not. So, anaerobic process is a preferable method to treat raw sewage sludge in the industry. The stable sewage sludge can be used as a soil conditioner or fertilizer (LudovicoSpinosa et al, 2001). There have two types of anaerobic digestion which are mesophilic and thermophilic digestion.

2.4.1 MESOPHILIC DIGESTION

Mesophilic digestion operates at ambient temperature at 35-45^{0}C. The optimum temperature of the mesophilic methane bacteria is 37^{0}C. For simplicity of the operation and to avoid the need to heat the reactor, most anaerobic digestion plants are operated at mesophilic temperatures that at temperatures between 3°C and 35°C and require 15 to 20 days of mean retention time in the digestion reactor, but it is not so efficient in reducing the total suspended solid and deactivation of pathogenic microorganisms.(Young-Chae Song et al,2004)

2.4.2 THERMOPHILIC DIGESTION

Thermophilic digestion using higher metabolic rate of thermophilic microorganisms has become a favourable technique recently. (Aoki N, Kawase M, 1991). Theoretically, the reaction rate of thermophilic digestion is double than mesophilic rate. The operation temperature of thermophilic process is between 55^0C to 60^0C. Although better performance of reduction of volatile solid and deactivation of pathogen organism can be obtained from thermophilic digestion, the effluent quality and ability of dewatering the residue is poor and required heat energy to heat the digester (FangHHP, ChungDWC, 1999; Maibaum C, Kuehn V.,1999; Kim M,2002). Moreover, the thermophilic digestion suffer from high amount of free ammonia, which plays an inhibiting role for the microorganisms; but the increasing pKa of the volatile fatty acid (VFA) will make the process more susceptible to inhibition(Boe K.,2006), thus make the thermophilic is very sensitive process than mesophilic process.

2.4.3 PROCESS THEORY

The anaerobic digestion process is composed of four stages: hydrolysis, acidogenesis, acetogenesis and methanogenesis (ZhijunWanga et al, 2008). Hydrolysis is the process where the sewage sludge is breakdown to their simple form. Acidogenesis or fermentation is the process where the acid-forming bacteria concert the simple form to short chain of organic acid. Acetogenesis is the process where the acetate is produce by the bacteria and the methanogenesis is the process where the process that produce methane gas and carbon dioxide (IzrailS.Turovskiy et al, 2006). The schematic below is the general reaction in anaerobic digestion.

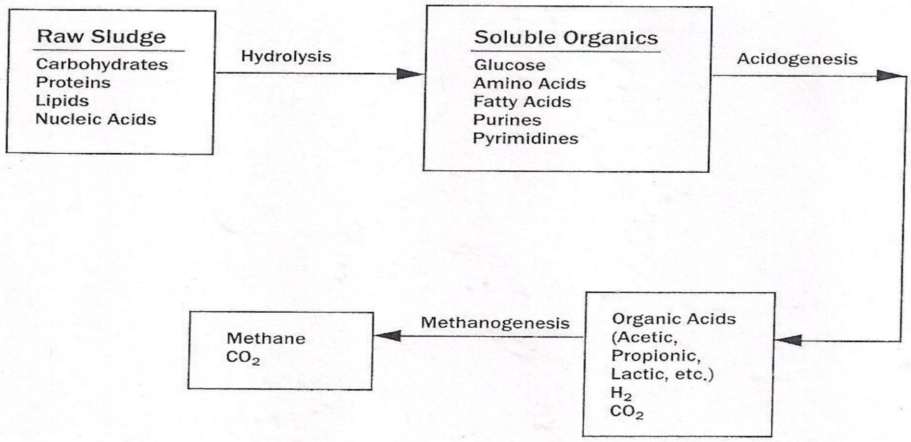

Figure 5.1 Schematic of reaction in anaerobic digestion.

Figure 2.2: Schematic Of Reaction in Anaerobic Digestion Taken from (IzrailS.Turovskiy et al, 2006)

2.5 ANAEROBIC MICROORGANISM

2.5.1 ACIDOGENIC BACTERIA

The essential organics in wastewater are proteins, lipids and hydrocarbon. All of it can be breakdown into simple monomer by acidogenic bacteria. Proteins are hydrolyzed into amino acid by protease enzyme. Lipids are converted from glycerin by lipase enzyme and the polymeric hydrocarbon are converted into glucose and other sugar via exo-enzyme (UdoWiesman et al,2007)

2.5.2 ACETOGENIC BACTERIA

Most of acetate is formed by synthrophic reaction, and only little of acetate is formed through direct fermentation (UdoWiesman et al, 2007). This bacterium is able to converted carbon dioxide into acetate via the acetylcoenzyme A (acetyl-CoA).

2.5.3 METHANOGENIC BACTERIA

There are 2 types of bacteria which are Methanosacina and methanothrix. It can grow using acetate. 70% of methane gas (CH_4) is formed in digester process. Methanosacina can produce ATP from acetate and water. Methanol and methyl amine are intermediate product that can be degraded down to methane gas (CH_4) and carbon dioxide (CO_2) (UdoWiesman et al, 2007).

2.6 FACTORS AFFECTING ANAEROBIC DIGESTION

As known, in the anaerobic process, it contains bacteria to consume all the organic matter in the raw sewage sludge. In order to run this process, it is necessary to provide optimum condition to bacteria to react with the sewage sludge. The factors that may affect the optimum condition are temperature, pH, nutrients and toxicants concentrations (LudovicoSpinosa et al, 2001). Table 2.1 shows the optimum operating conditions for anaerobic sludge digestion:

Table 2.1: Optimum Condition for Anaerobic Digestion Taken from (LudovicoSpinosa et al, 2001)

Table 13.1. Optimum and extreme operating conditions for anaerobic sludge digestion

Variable	Optimum	Extreme
pH	6.8–7.4	6.3–7.9
Oxidation reduction potential (mV)	−520 to −530	−490 to −550
Volatile acids (mmol/L)	0.8–8.0	>35.0
Alkalinity (mg/L as $CaCO_3$)	1300–3000	1000–5000
Organic loading rate (as volatile solids)		
Mesophilic (kg/m^3/d)	0.8–2.0	0.4–6.4
Thermophilic (kg/m^3/d)	1.5–5.0	1.0–7.5
Temperature		
Mesophilic (°C)	32–37	20–42
Thermophilic (°C)	50–56	45–65
Hydraulic retention time (days)	12–18	7–30
Biogas composition		
Methane (% vol)	65–70	60–75
Carbon dioxide (% vol)	30–35	25–40

2.6.1 pH

pH is one of the important factor that can affect the performance of the anaerobic process since methane bacteria is sensitive to pH. Methane bacteria will growth at all pH values between 6.5 and 7.2 (Boe K,2006) but the optimum condition of methane bacteria to growth is at 7.0 – 7.2. The acidogenesis organism is less sensitive and can live in wide range of pH between 4.0 and 8.5(Hwang MH et al,2004).At low pH the main product are acetic and butyric acid while at pH of 8.0, acetic and propionic acid are produced (Boe K.,2006). The volatile fatty acid produce during the process tend to reduce pH of the system. Normally, the activity of methanogenic bacteria countered the system pH by produced alkalinity in a form of carbon dioxide, ammonia and bicarbonate (Turovskiy IS, Mathai PK, 2006; Hwang MH et al, 2004).The system pH are controlled by CO_2 concentration in gas phase and HCO_3 alkalinity in liquid phase (Lise Appels et al , 2008). If concentration of CO_2 is remain constant in the digester, the HCO_3 may be added to the system to maintained the alkalinity of the system.

2.6.2 TEMPERATURE

The most importance factor that affects the digestion performance and the production of biogas is temperature. Anaerobic bacteria can stand temperature ranging from below freezing to above 57^0C but the desired temperature for mesophilic is at 37^0C and for thermophilic is at 54.4^0C. The bacteria activity and the production of gas are fall off significantly between temperatures of $39\text{-}51.7^0$C.

In the thermophilic range, the production of biogas and decomposition occur more rapidly than in the mesophilic range but it is highly sensitive to the changes in temperature or composition of the feed materials. All the anaerobic digestion reduces the organic matter and pathogens but in the thermophilic digestion the rate of destruction is high. Although the mesophilic process is slower than thermophilic, the process is less sensitive to changes and produces more methane gas (Ivo Achu Nges and Jing Liu, 2010).

The temperature of the digester must be keep at the consistent temperature to optimize the digestion process because the rapid changes will upset bacterial activity. In United state, digester vessel required some level of insulation or heating to maximize the production of gas.

2.6.3 HYRAULIC RETENTION TIME (HRT)

Hydraulic retention time (HRT) is a measure of the average length of time that microorganism needs to digest the biodegradable material in the reactor. HRT is depending on the sewage sludge characteristics and environmental condition. The digester must reach suitable HRT in order to achieve better process. The poor degradation of colloidal particles has resulted in long retention times (20-30 days) in anaerobic processes (Parawira et al,2004) and above 35 days in some full-scale operations primarily designed for wastes stabilization. Sludge digestion at shorter SRT has been reported by Appels et al (2008) in thermophilic digestion.. However, a major drawback that comes with shortening of the SRT could be the poor destruction of volatile solids (Appels et al, 2008), a condition which will lead to an increase in the volume of residual sludge for further disposal.